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Development of a 2012 model for the ${}^6\text{Li}$ time analyzer detector systemS. Satoh^{a*}^aHigh Energy Accelerator Research Organization (KEK), Oho 1-1, Tsukuba-shi, Ibaraki 305-0803, Japan

Abstract

Neutron scattering experiments are indispensable for the structural analysis of substances. Large-scale experimental facilities are constructed all over the world. However, there are not enough detectors that detect neutrons well because a neutron is difficult to detect directly. A ${}^3\text{He}$ gas detector, which is most often used, is the most ideal detector for neutrons; however, it has a low counting rate and low position resolution. A 2012 model for the ${}^6\text{Li}$ time analyzer (LiTA12) system is developed for overcoming the weaknesses of the ${}^3\text{He}$ detector. The LiTA12 system is a two-dimensional (2-D) detector system that has a high count rate and a comparatively high position resolution. Furthermore, the LiTA12 system attains a high counting rate of 1.2 million counts per second per square centimeter, a position resolution of 3 mm, and a detection area of $5\text{ cm} \times 5\text{ cm}$. The detection efficiency of the system is approximately 48% compared to that of a ${}^3\text{He}$ detector. The LiTA12 system is expected to be used in high-counting-rate neutron experiments such as small-angle scattering experiments.

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Keywords: J-PARC; neutron detector; ${}^6\text{Li}$ time analyzer; LiTA; high counting rate.

1. Introduction

Various types of detector systems have been developed in the KENS-DAQ group at the Neutron Science Laboratory (KENS) in the High-Energy Accelerator Research Organization (KEK), which was established to develop data acquisition (DAQ) electronics and software for experimental spectrometers used at the Materials and Life Science Experimental Facility (MLF) in the Japan Proton Accelerator Research Complex (J-PARC). For example, a neutron encode-module with network (NEUNET) system

* Corresponding author. Tel.: +81-29-864-5200-4517

E-mail address: setsuo.satoh@kek.jp

[1] for ^3He gas detectors, which is the de-facto standard in J-PARC/MLF, was developed by the group. The system is used in more than half of the experimental spectrometers there and is able to control thousands of ^3He gas detectors that are one-dimensional position detectors.

A ^6Li time analyzer (LiTA) system [2] was also developed by the group as a high count rate and high efficiency detector 6–10 years ago, and it is still used in some experimental spectrometers. However, the LiTA system is large and unstable. Therefore, a 2012 model for the ^6Li time analyzer (LiTA12) system has been developed, which is updated with newer parts, is reduced to approximately one-quarter of the size of the old one, and operates stably.

The LiTA12 system performs data processing of a LiTA detector that consists of ^6Li glass scintillators (GS20) and a multi-anode photomultiplier tube (MA-PMT, H9500 by Hamamatsu Photonics). The size of the scintillator is $2.1\text{ mm} \times 2.1\text{ mm} \times 1\text{ mm}$. The scintillators are arranged as a 16×16 matrix with a 3.04-mm pitch corresponding to each anode of the MA-PMT. The LiTA12 system has data acquisition circuits for each anode independently for a high counting rate.

The LiTA12 system has a $49\text{ mm} \times 49\text{ mm}$ detection area and has obtained 28 million counts per second (Mcps). In other words, a neutron detector system that exceeds a neutron counting rate of 1 Mcps/cm² has finally been realized. The neutron detection efficiency of the system is approximately 48% compared to that of a ^3He detector. Although the highest counting rate of the system is slightly reduced, an event function has also been added to the system for the purpose of off-line analysis and crosstalk prevention.

2. LiTA12 system

2.1. Neutron detection

The LiTA12 system consists of one LiTA detector, eight fast amplifier (FAMP) boards, and four LiTA12-Versa Module Europe (VME) modules. The FAMP boards amplify 256 signals from the detector, and these signals are accumulated as histogram data by the VME modules. Fig. 1 shows the main parts of the LiTA12 system.

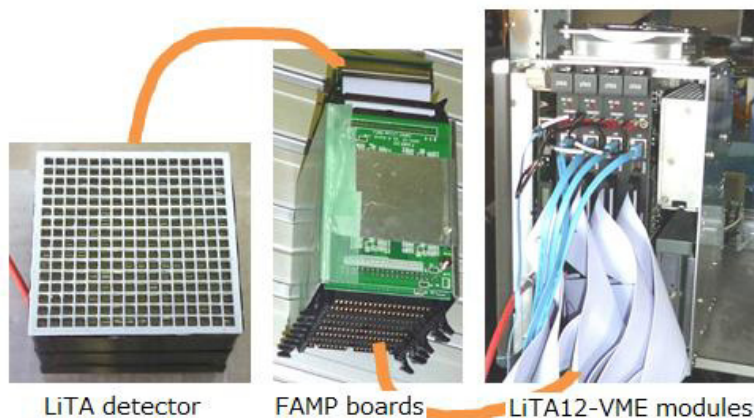


Fig. 1. Main parts of the LiTA12 system.

The LiTA12-VME module has four analog-to-digital converter (ADC) boards, and each board has sixteen 40-MHz 10-bit ADCs. In order to realize low power consumption and stable operation, the sampling frequency of the ADC needs to be maintained at a lower frequency. A low-pass filter is placed at the ADC input in order to filter signals with a frequency greater than the Nyquist frequency. The time constant of the filter is 150 ns and is equivalent to the luminescence time of the ^6Li glass scintillator. An FPGA on the ADC board continuously watches for the converted signal from the ADC, detects a pulse with a width of approximately 150 ns, searches for a peak level, subtracts a pedestal level monitored continuously, and stores the result as a peak value. If the peak value exceeds the threshold level that is set for every pixel, it is saved along with the time stamp of the time of flight (TOF) as neutron data.

2.2. Histogram function

A histogram function is executed in the FPGA on the ADC board. Fig. 2 shows a block diagram of the LiTA12 system. The histogram function creates two types of histograms: one is a time-analyzing histogram, and the other is a pulse-height analyzing histogram. The time-analyzing histogram has 16,384 channels for each pixel in a memory IC that is distributed for each of the eight pixels on the board. The time resolution of the histogram can be set from 40 ns to 1.3 ms with a unit of 20 ns. The pulse-height analyzing histogram has 512 channels for each pixel in the internal memory of the FPGA. A PC can read these data at any time.

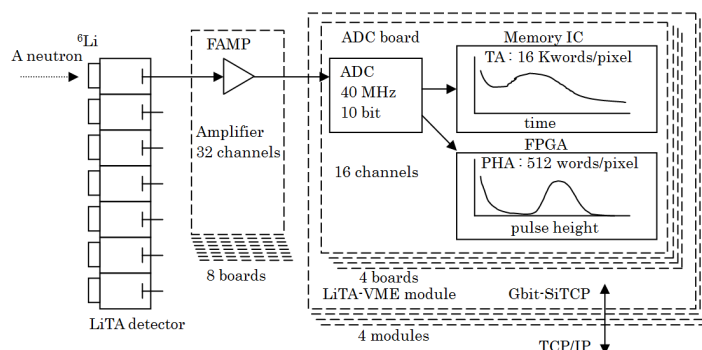


Fig. 2. Block diagram of the LiTA12 system.

Because it takes 100 ns to store the data for one neutron, it takes 800 ns if eight pixels detect neutrons simultaneously. The histogram function is expected to obtain 1.25 Mcps/pixel as the maximum counting rate. Using a test pulse generator, the system has operated normally at rates up to 1.19 Mcps/pixel. Because a read-out time is also needed, the maximum counting rate is lower than expected. Nevertheless, the histogram function should be able to count up to 305 Mcps for the entire system.

2.3. Event function

The event function, which is on the LiTA12-VME module, operates on the basis of the data collected from each ADC board. The same data from the histogram function are modified to event data and are transferred to the PC. The event data (64 bits) consist of a header (8 bits), TOF time (24 bits), pixel number (14 bits), pulse height (10 bits), and reserve (8 bits). A new exclusive function prevents crosstalk and reduces the data size. A neutron that glimmers in the scintillator generates several signals by the

crosstalk condition. Therefore, the exclusive function selects the maximum signal for the neutron and eliminates the other signals. In practice, the exclusive function operates as follows. The maximum peaks are searched within the 16 domains of the detector, are compared with each other every 160 ns, and are transferred to the PC as event data. The four VME modules are connected by cables to each other to compare mutual data.

3. Verification experiments

3.1. Maximum counting rate

The maximum counting rate of the LiTA12 system is measured by changing the neutron beam size at BL16 of J-PARC/MLF. The beam of BL16 is a pulsed neutron source that prevents a burst of neutrons by a T0-chopper. The maximum counting rate of the LiTA12 system is 28 Mcps (1.2 Mcps/cm²). Fig. 3 shows the neutron beam size versus the maximum count rate of the LiTA12 system.

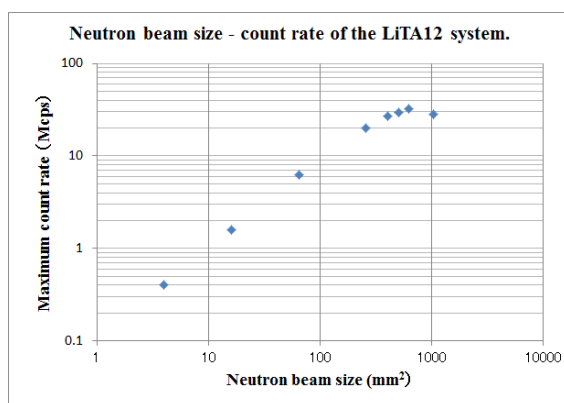


Fig. 3. Neutron beam size versus the count rate of the LiTA12 system.

3.2. Cadmium “K” character

A “K” character created from cadmium is measured at the B-3 beam port in the Kyoto University Reactor (KUR). Fig. 4 shows the pulse-height distributions (the left-hand side) and the 2-D graph (the right-hand side) using a wide neutron beam and the cadmium “K” character. The 2-D graph of the x-position versus the y-position exhibits very good contrast of a shadow of cadmium.

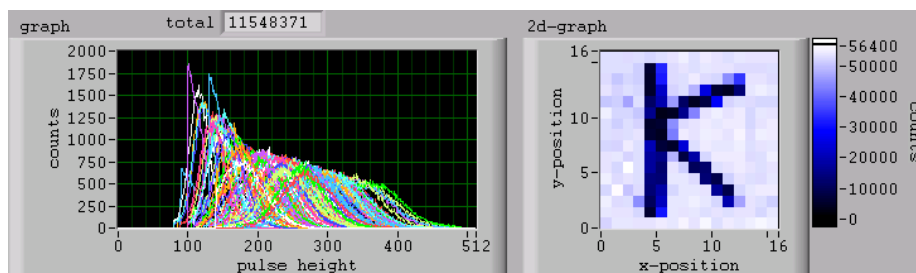


Fig. 4. Pulse-height distributions of all pixels and a two-dimensional (2-D) graph of the “K” character.

3.3. Narrow neutron beam

The system is measured with a neutron beam collimated to an area of $2\text{ mm} \times 2\text{ mm}$ at the B-3 beam port in KUR. The narrow neutron beam hits only one pixel scintillator of the LiTA detector. Fig. 5 shows the pulse-height distributions (the left-hand side) and the 2-D graph (the right-hand side) with a much lower threshold level than the usual level. Each of the four surrounding pixels, which are the low pulses, has the same number of counts as the center pixel. This result means that there is crosstalk between each pixel, although the ^6Li glass scintillators are cut smaller to prevent any crosstalk. Because a vacuum tube with a thick glass wall exists from the surface to the inside cathode, the light of the center pixel is scattered to the surrounding pixels inside the MA-PMT. However, the surrounding pulses have a low enough intensity relative to the center pulse, and they are easily eliminated.

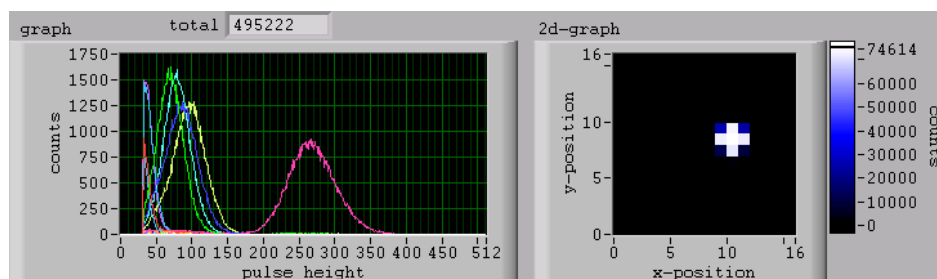


Fig. 5. Pulse-height distributions of all pixels and a 2-D graph using the narrow neutron beam.

3.4. LED test pulse

The crosstalk that originates in the MA-PMT is generated and prevented by the exclusive function using an LED test signal. First, the same data of the neutron experiment with crosstalk are obtained without the exclusive function as in Fig. 5. Next, the original data without crosstalk are obtained with the exclusive function within an accuracy of 0.1% for the test pulse counts.

4. Summary

A maximum counting rate of up to 28 Mcps for the LiTA12 system was obtained by using a powerful neutron source at J-PARC. Therefore, a neutron detector system that exceeds 1 Mcps/cm^2 was completed.

It was confirmed that crosstalk was generated within the MA-PMT. This crosstalk can be eliminated by using proper threshold levels for each pixel. In the event function, the exclusive function was able to eliminate crosstalk in hardware.

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